Abstract

Renewable energy sources such as photovoltaic (PV) modules, wind and fuel cells require power converters to convert their energy into standardized regulated ac output. The design and control of the power converters affect the major performance parameters such as efficiency, power quality and reliability. The motivation of this thesis is to achieve high performance of the power converters with renewable energy source such as PV modules as the input. Two transformer-isolated power circuit topologies with input voltage of less than $50V$ are designed and developed for low and medium power applications. Various design and control issues of these converters are identified and new solutions are proposed.

For low power rating of a few hundred watts, a line-frequency transformer interfaced inverter is developed. In the grid connected operation, it is observed that this topology injects considerable lower order harmonics in the grid current. The reasons for this are identified as mainly the distorted magnetizing current of the transformer, dead-time effect and dc offset injection to the transformer primary. The dc offset injection causes even harmonics in the grid current. A new current control is proposed to attenuate the lower order harmonics. The proposed method consists of adaptive harmonic attenuation block for the odd harmonics. A proportional-resonant-integral (PRI) controller is proposed to eliminate the dc offsets and hence the even harmonics. A systematic design method is proposed to select the controller gains. The proposed control has reduced resource utilization in the digital implementation compared to state-of-the-art current control techniques. The performance of the system with the proposed current control is validated experimentally. The proposed current control effectively attenuates the lower order harmonics and the resulting grid current complies to the harmonic limits set by the grid interconnection standard IEEE 1547-2003.

For grid connected operation, phase-locked loops (PLLs) are used for grid synchronization of the power converters. The PLLs considered in the thesis are the low-complexity PLLs such as synchronous reference frame PLL (SRF-PLL) and second-order generalized integrator (SOGI) based PLLs for three-phase and single-phase systems respectively. The effect of grid voltage non-idealities such as unbalance, harmonics, dc offsets and frequency deviation on the unit vectors of these PLLs is analytically quantified. It is shown that the unit vectors can contain harmonic distortion and dc offsets which is undesirable. This is because the unit vectors are used for closed-loop control reference generation. New systematic designs are proposed for these PLLs. The proposed designs achieve fastest settling time for these PLLs for a given worst-case input condition. The unit vectors are ensured to contain harmonic distortion and dc offsets well within the limits set by the standard IEEE 1547-2003. The proposed designs can be used to achieve very good performance using conventional low-complexity PLLs without the requirement of advanced PLLs which are computationally intensive.

For power ratings of a few kilowatts upto $10kW$, a high-frequency (HF) transformer interfaced ac link inverter is developed. A lossless snubber is used for this topology to suppress the possible over-voltage spikes due to current commutation in the transformer leakage inductance. As this is a low voltage and high current topology in the input side, paralleling MOSFETs in the HF inverter is used for reduction of conduction losses. A method to select optimal number of paralleled MOSFETs is proposed. The thermal modelling and thermal mismatch issues in paralleled surface mount device MOSFETs are analyzed.

A new synchronized modulation method is proposed which effectively suppresses the over-voltage spikes. The effect of the system non-ideality of turn-on delay or dead-time on the performance of this topology is analyzed in detail and a new solution is proposed. The proposed modulation results in soft switching of the HF inverter, rectifier and snubber devices which improves the system efficiency. The problem of spurious turn-on pulses in the HF inverter devices due to the conventional turn-on delay is also solved which improves the system reliability. A new start-up method is proposed which ensures reliable start-up of the inverter topology without any undesirable over-voltage or inrush currents. The proposed start-up method does not require any additional circuitry. The performance of the proposed modulation and start-up method is validated using simulation and experimental results.

The overall research work reported in the thesis shows that it is possible to have compact, reliable and high performance power converters for renewable energy conversion systems. It is also shown that high control performance and power quality can be achieved using the proposed control techniques of low implementation complexity.